Detecting individual QSO HII regions during Reionization Era in HI 21cm maps

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High redshift QSO surveys

Several ongoing efforts with infrared telescopes

- Sloan Digital Sky Survey (SDSS)
  (Fan et al. 2001, 2006; Jiang et al. 2008)

- Canada-France High Redshift QSO survey (CFHQS)
  (Willott et al. 2007, 2010).

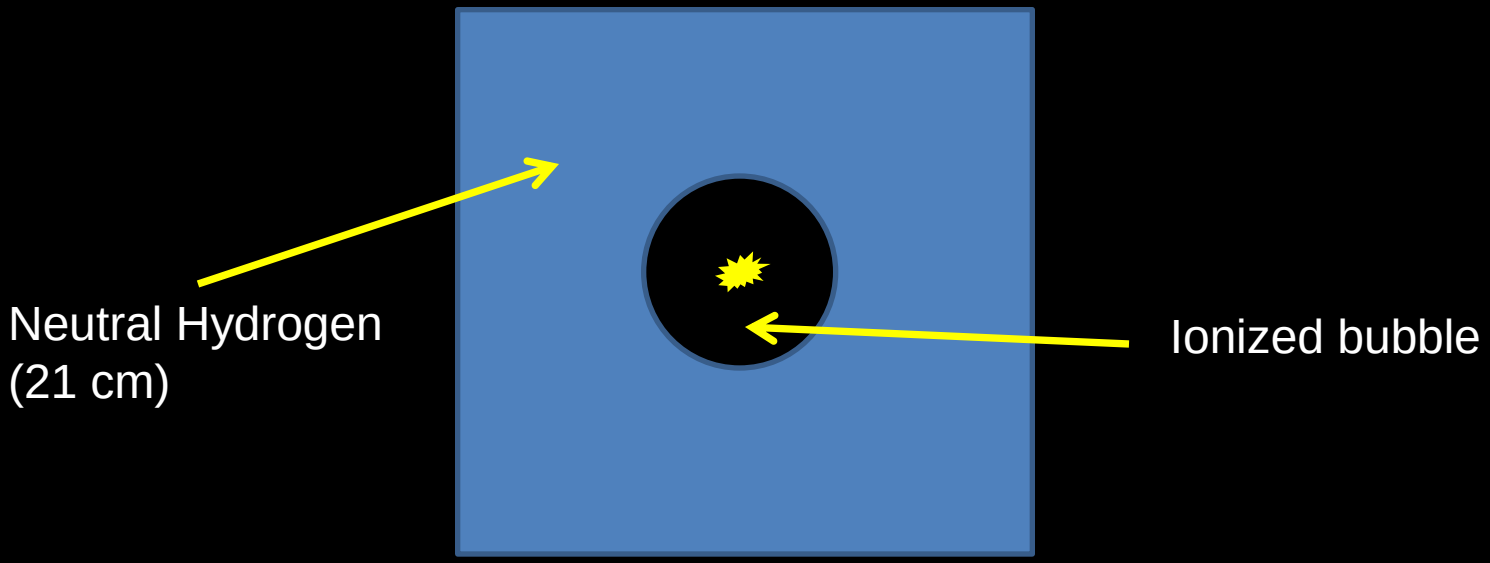
- UKIRT Infrared Deep Sky Survey (UKIDSS)
  (Mortlock et al. 2011).

Found QSO at redshift z~7.1

Motivation

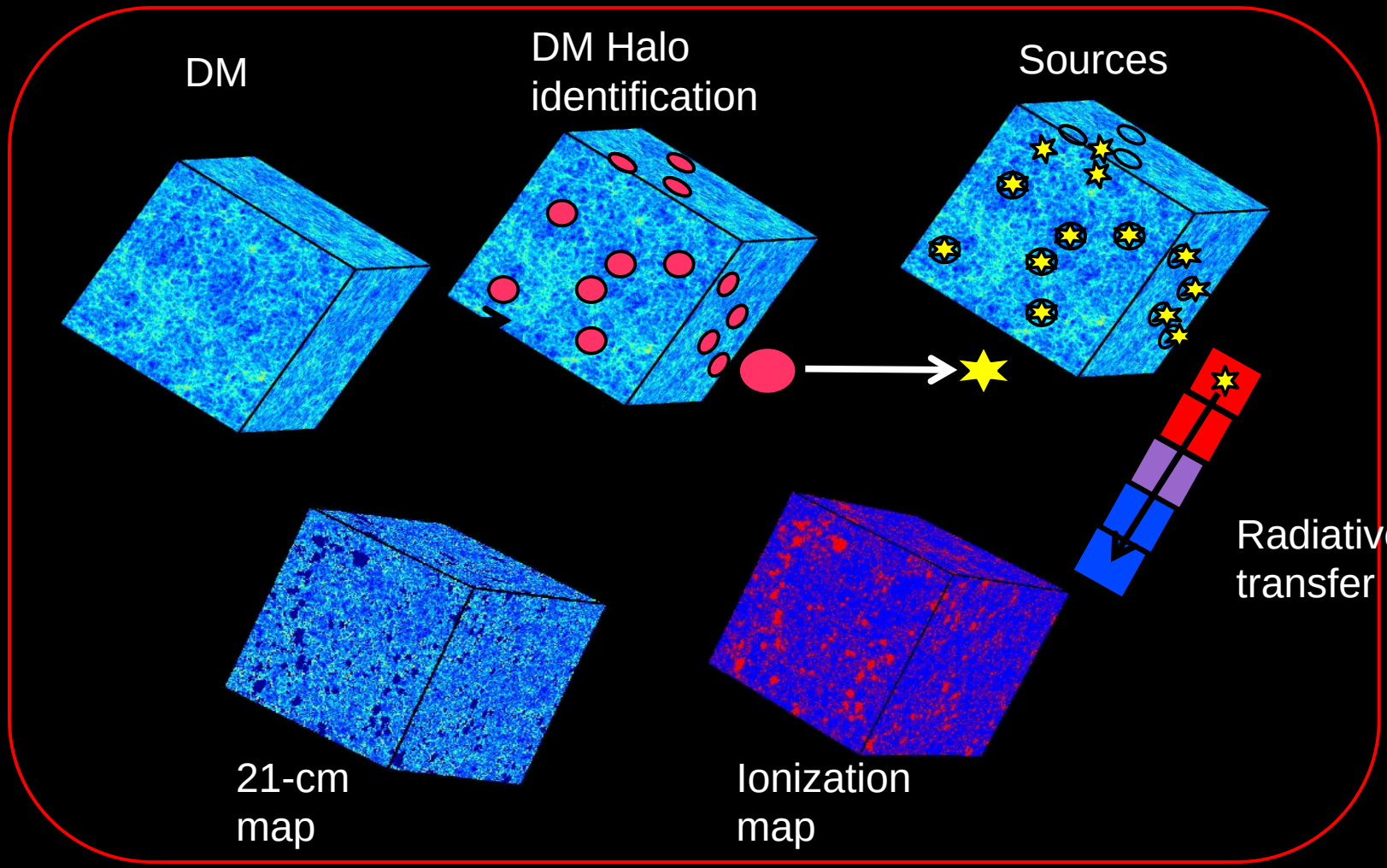
- Sizes of ionized regions around bright QSOs
- Constrain the QSO properties such as luminosity, age etc.
- Measurments of the IGM properties such as neutral Hydrogen fraction
- Role of QSOs during reionization

Detecting QSOs in HI 21-cm maps



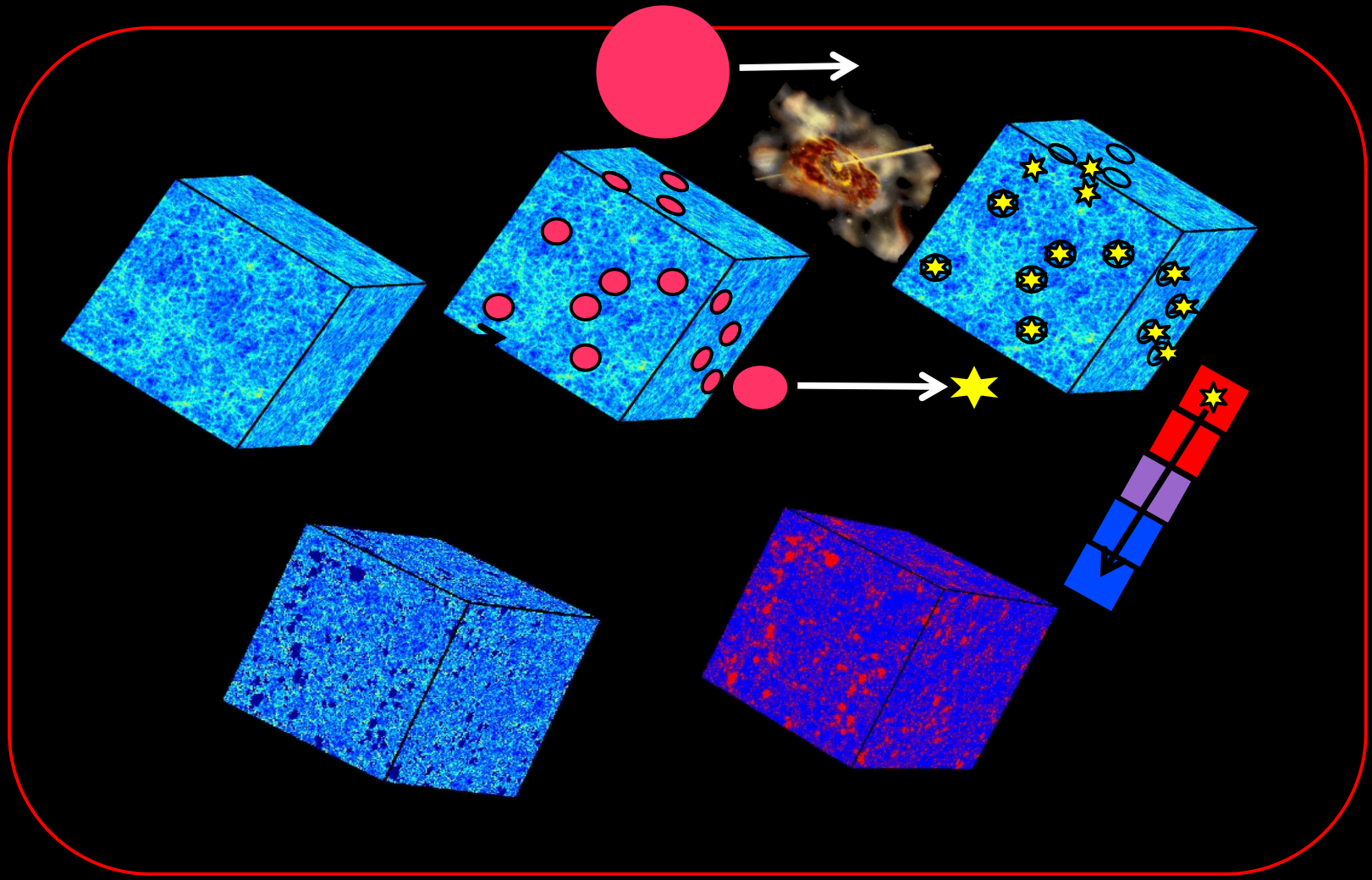
- How does a QSO H II bubble look like ? Are they different from ionized bubbles around galaxies?
- Can LOFAR like telescope (or MWA, GMRT) be used to detect individual H II regions around QSOs and galaxies ?
- what can we learn from such observations?

Reionization Simulations：without QSOs



Reionization Simulations : with QSOs

Quasars



Reionization Simulations：with QSOs

QSO luminosity and host dark matter halo mass relation

(1)The quasar luminosity *can be connected to the black* hole mass

(2) *Black hole mass can be connected to the mass of galaxy bulges MB* (Maggorian-type relation; Magorrian et al. 1998).

(3) *MB can be connected to the total mass of the halo*

$$L_{\rm QSO} = KM_{\rm h}$$

Simulations with QSO

Table 1. Summary of important quantities of the three simulated cases.

	Resolution (cMpc)	Box (sub-box) size (cMpc)	z (QSO on)	z (QSO on +11.5 Myr)	z (QSO on +23.0 Myr)
Early QSO	0.64	163	8.636	8.515	8.397
Late QSO	0.64	163	7.760	7.664	7.570
Large box	1.2	607 (242)	7.760	7.664	7.570

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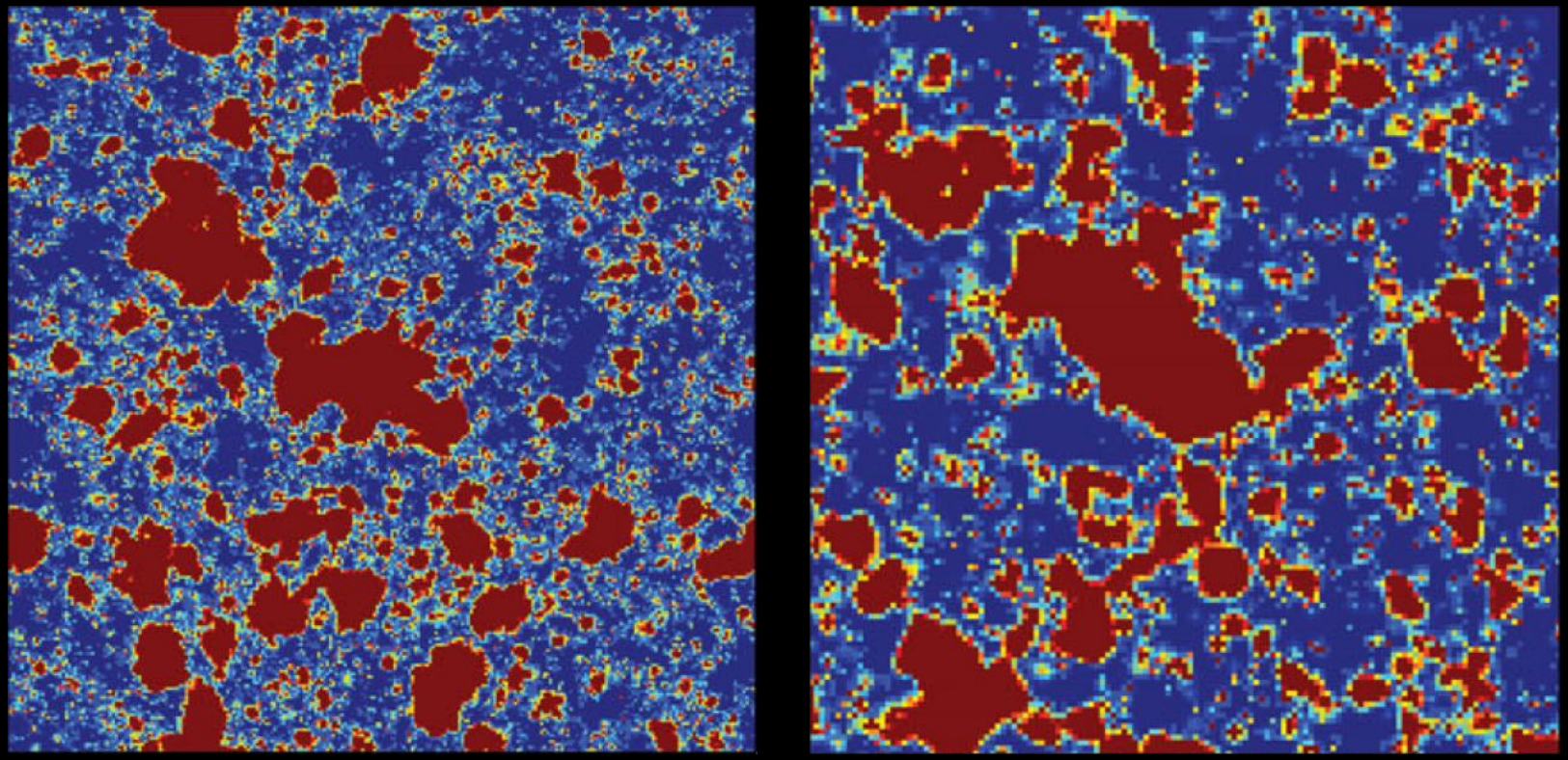
QSO H II regions

Time=0 Myr



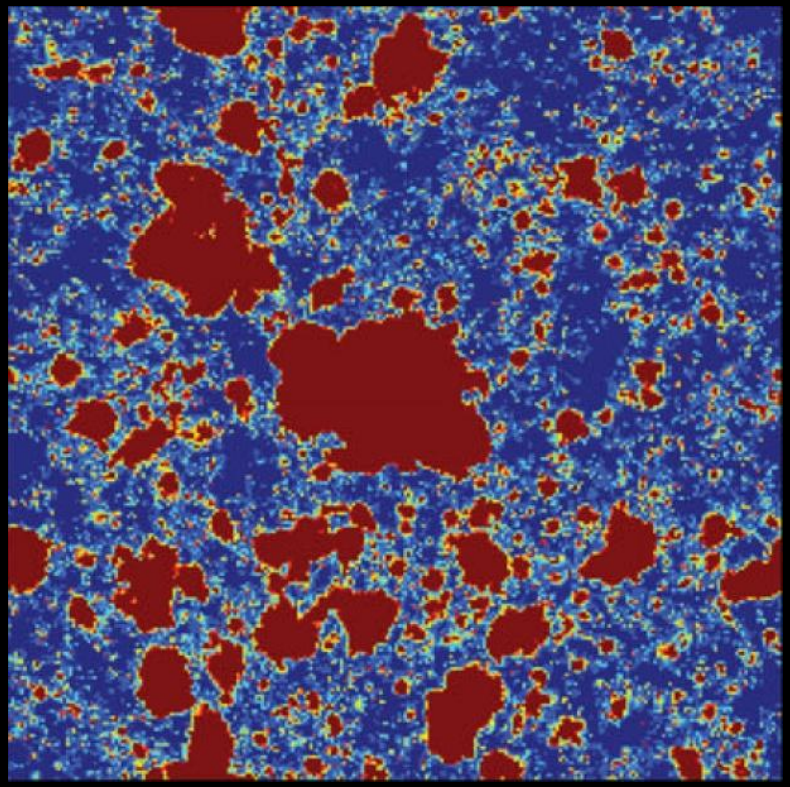
163 Mpc

~50% ionized by stars

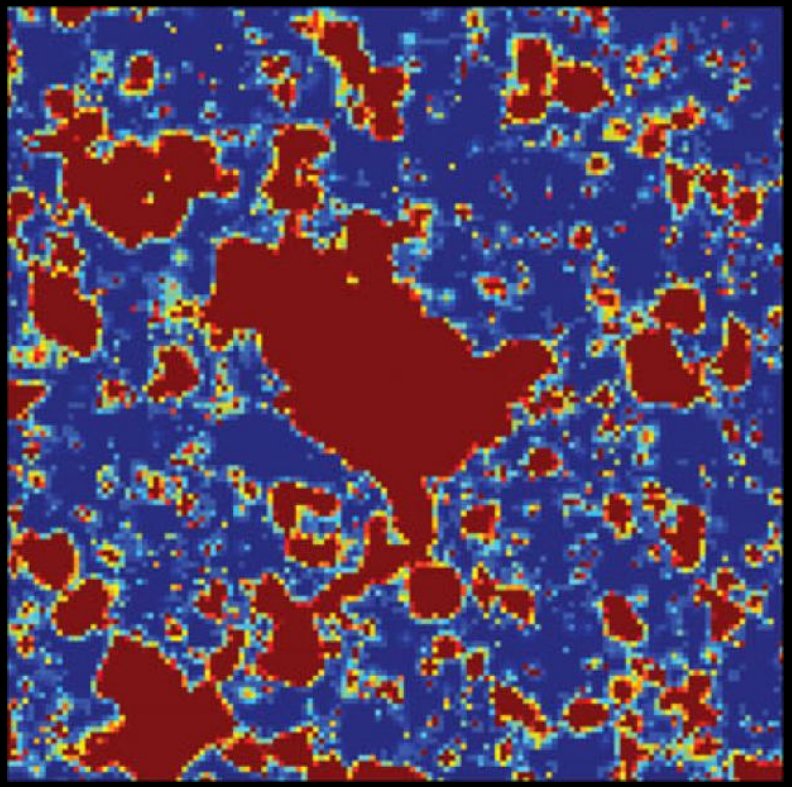
607 Mpc

QSO H II regions

Time=11.5 Myr



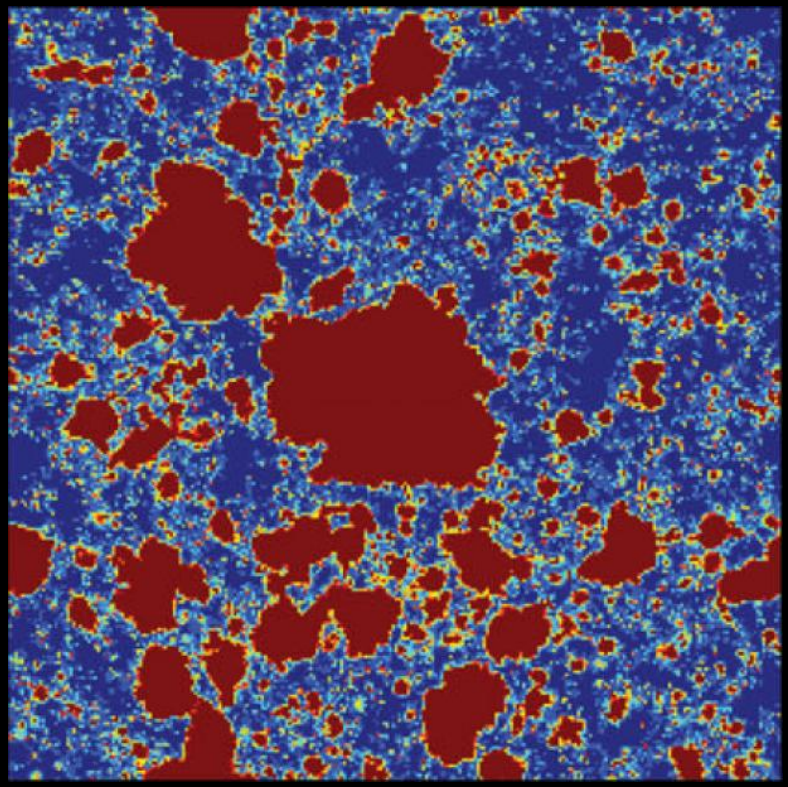
163 Mpc



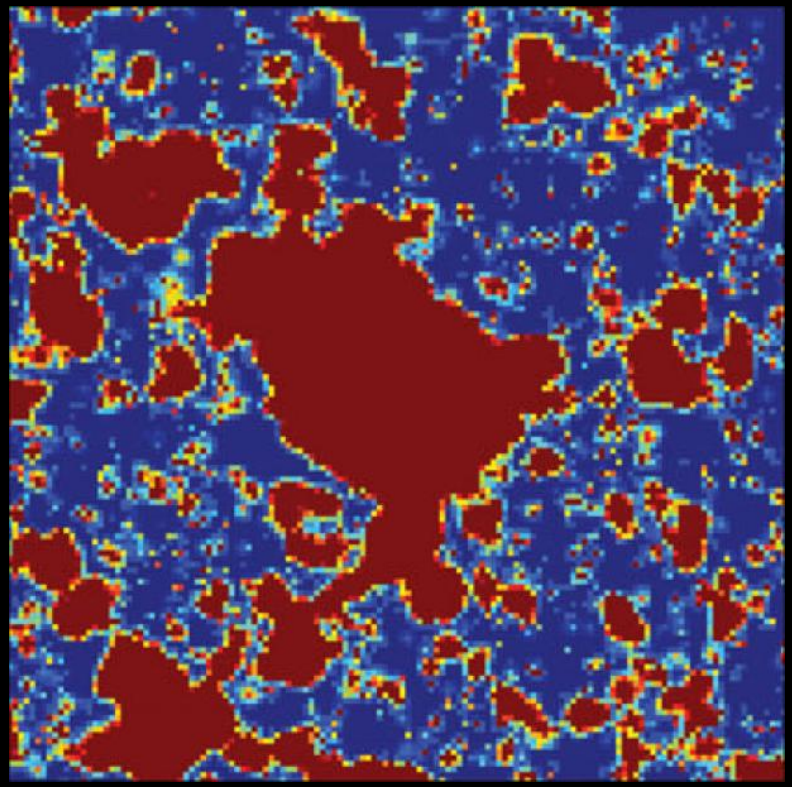
607 Mpc

QSO H II regions

Time=23.0 Myr



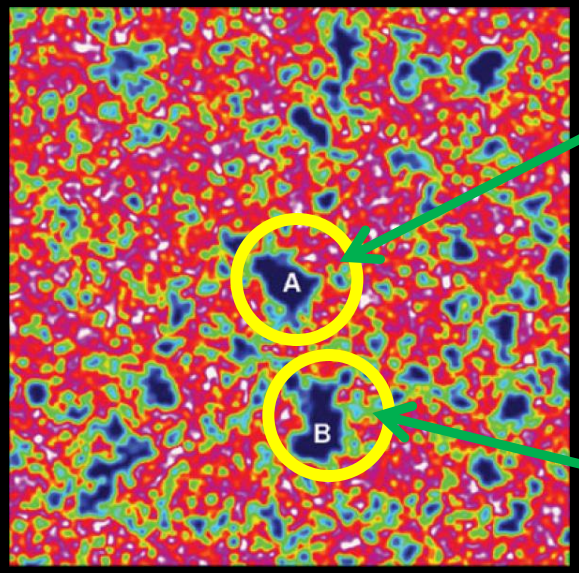
163 Mpc



607 Mpc

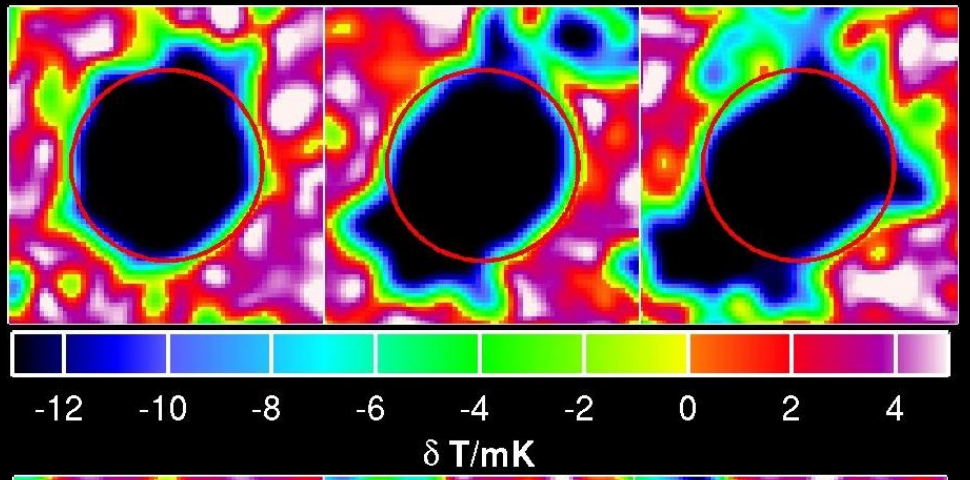
Datta et al, 2012, MNRAS, 424, Issue 1, pp. 762

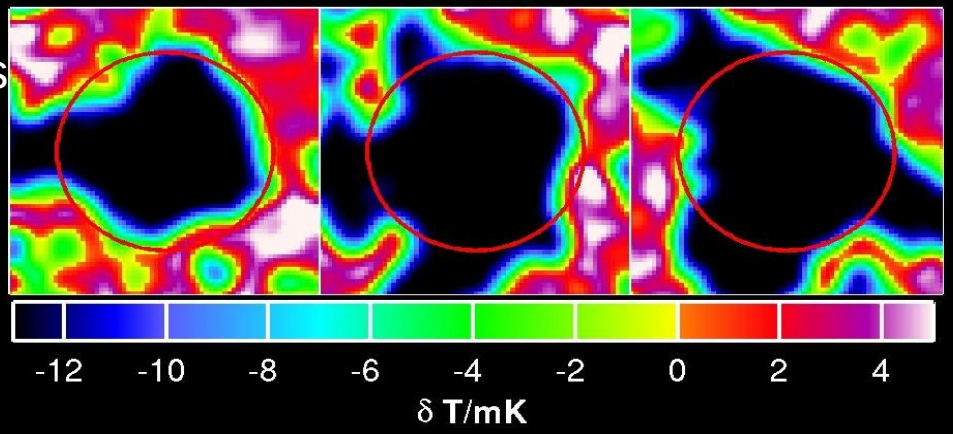
QSO and galaxy H II regions

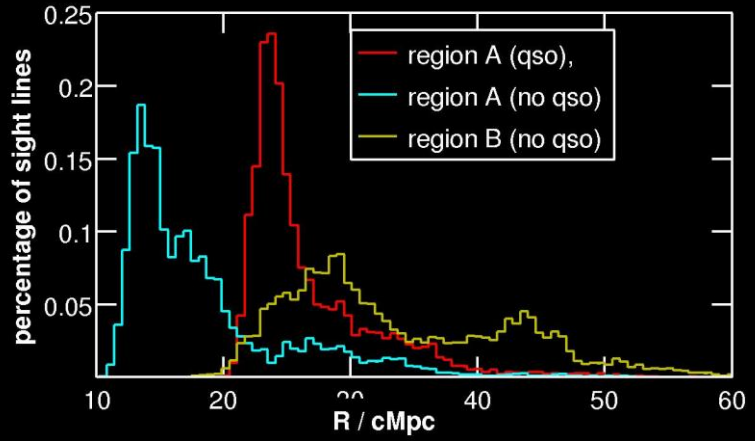


QSO bubble

Cluster of galaxies bubble







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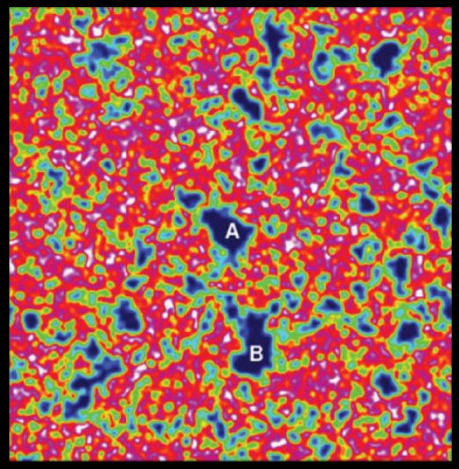
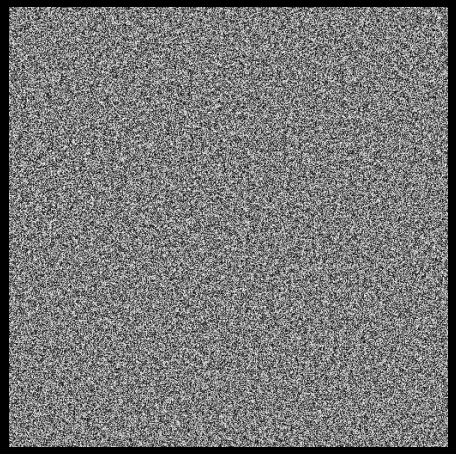
Reionization 21-cm signal and its detection

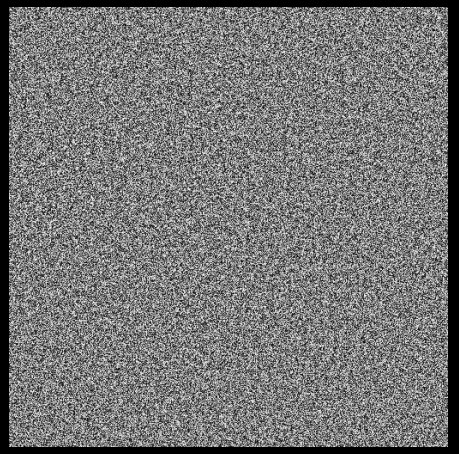
21 cm signal



Instrument Noise



Signal+Noise



Signal rms ~ 5 -10 mK

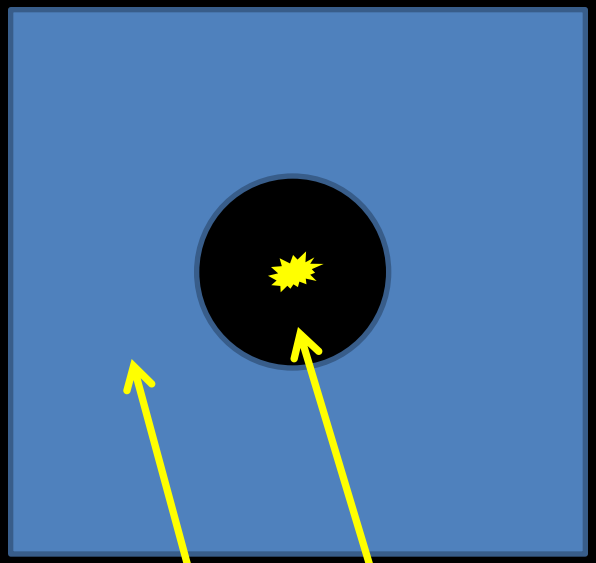
Noise rms ~ 70 -100 mK

~~Imaging~~

(But, see Zaroubi et al 2012)

Statistical detection of 21 cm signal has been proposed !!!

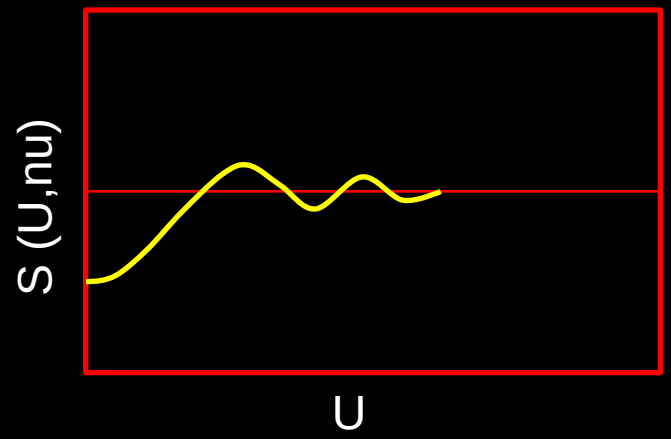
Detecting ionied bubble in 21 cm observations



Neutral Hydrogen
(21 cm)

Ionized bubble

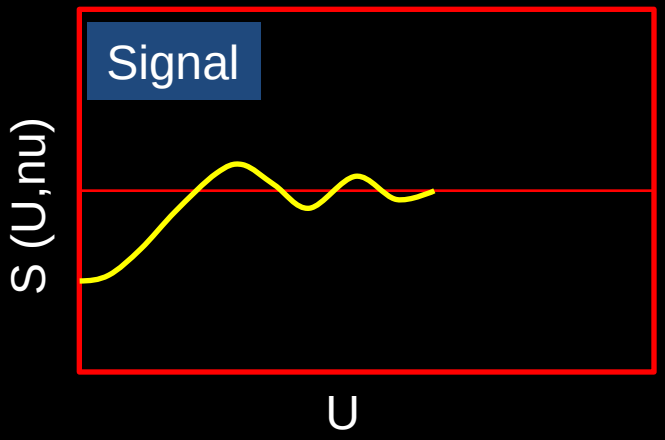
U=d/lambda

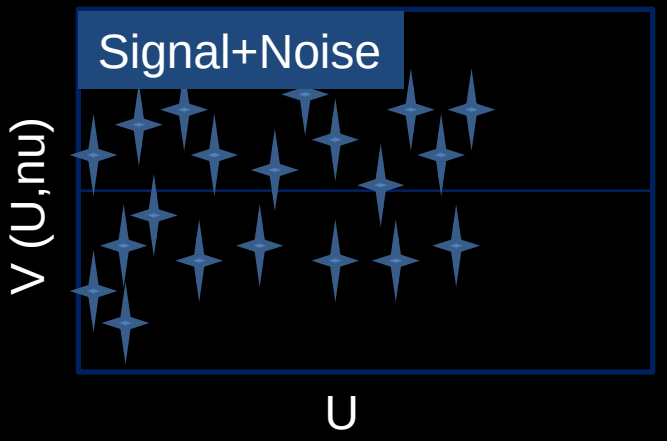


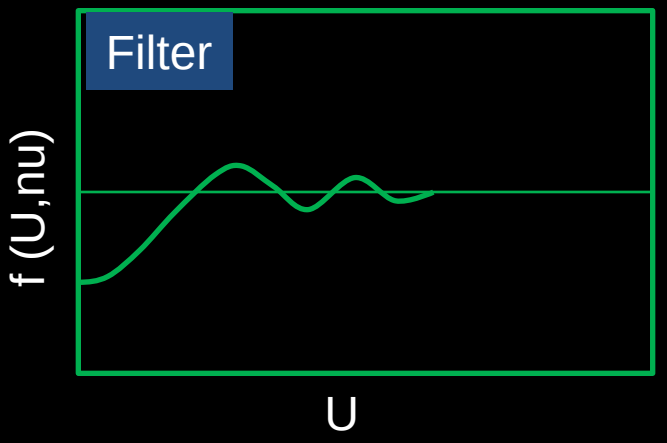
Signal Observed by
Radio Interferometer (e.g, LOFAR)

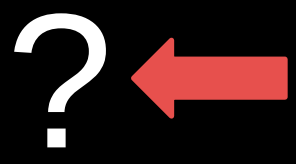
Matched filter technique

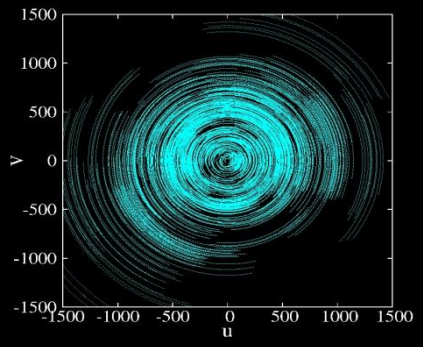
Datta et al 2007,2008
2009, 2012
Majumdar et al 2011,2012











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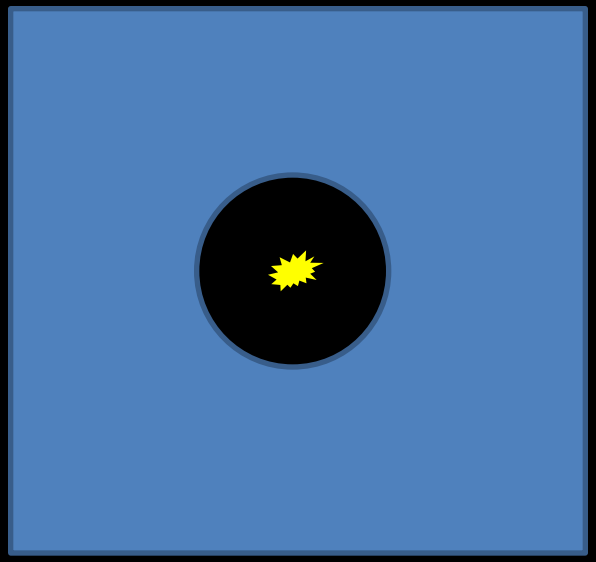

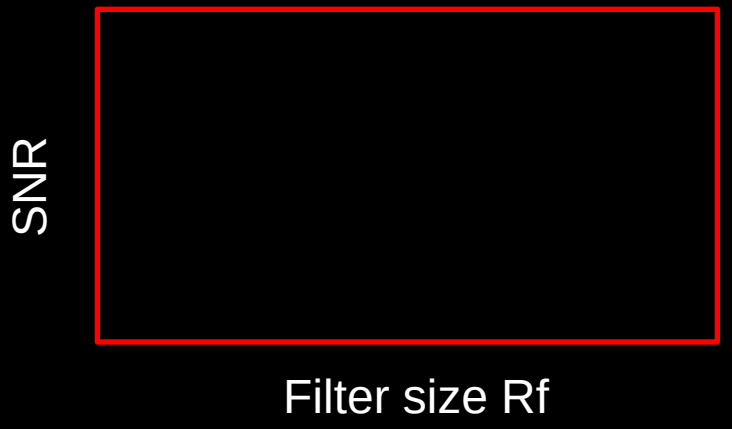

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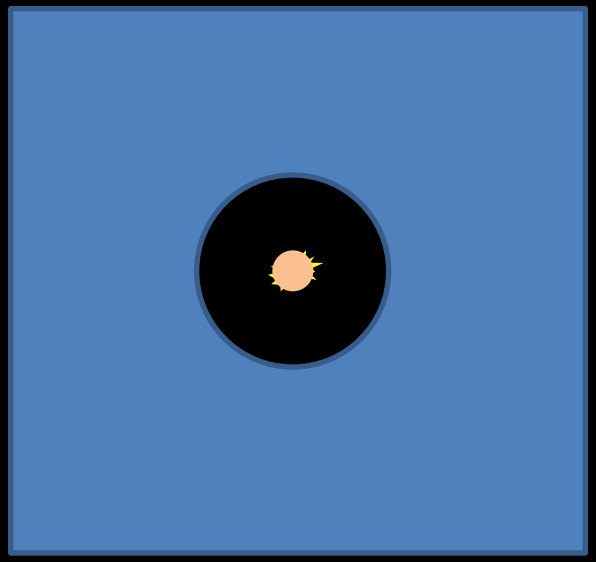

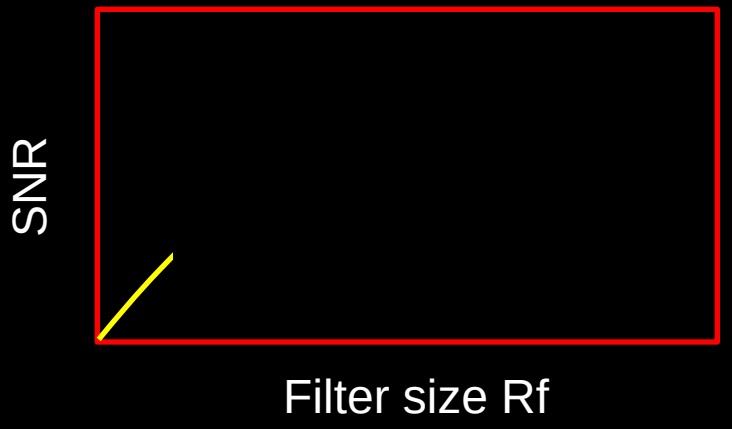

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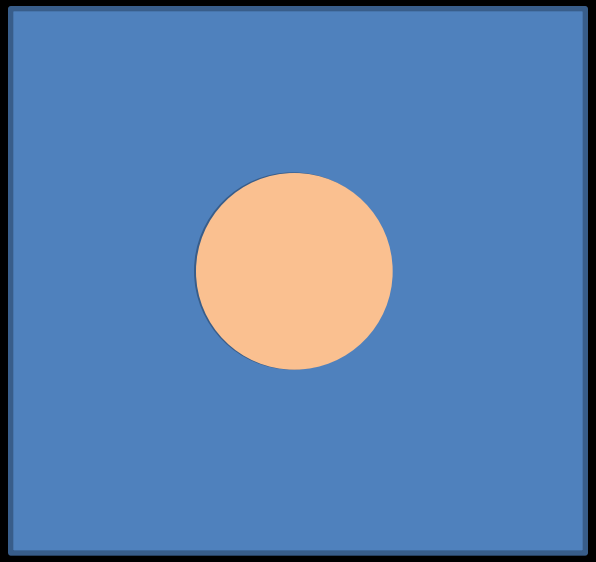

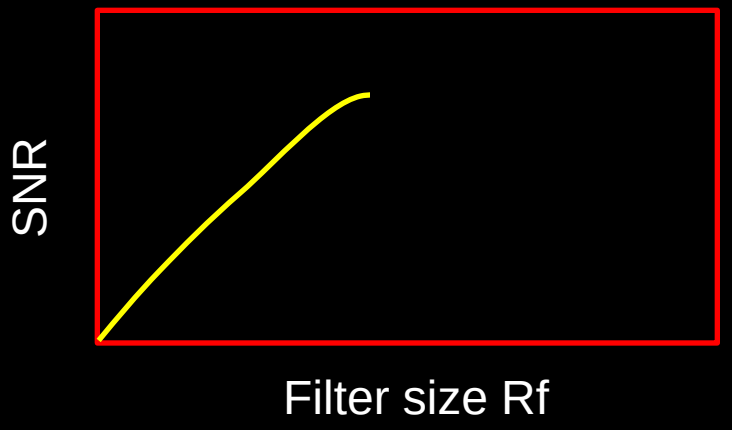

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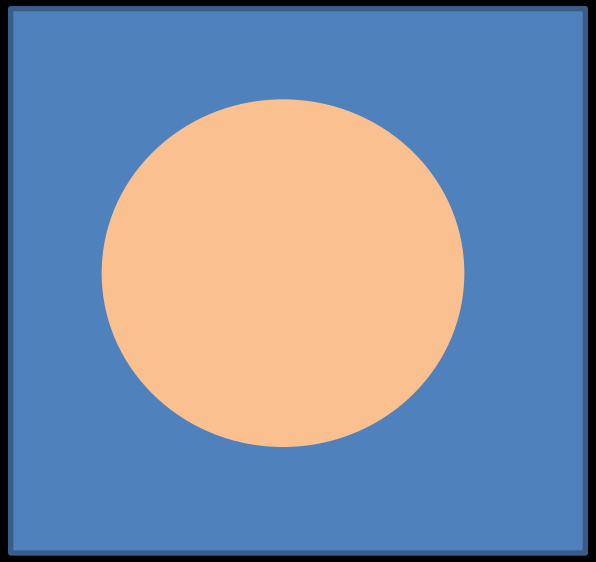
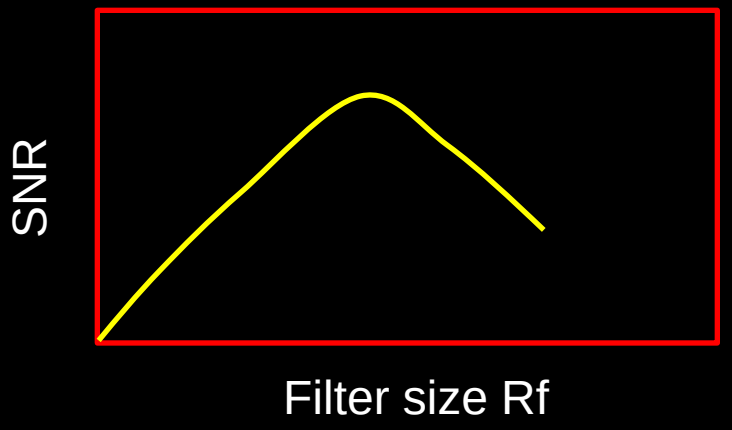
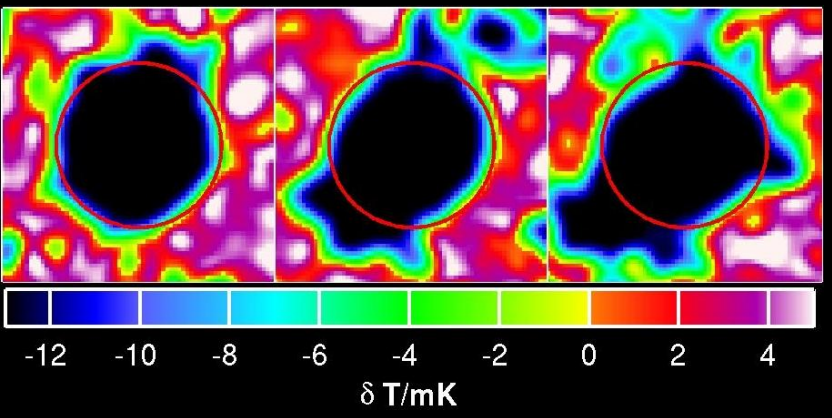
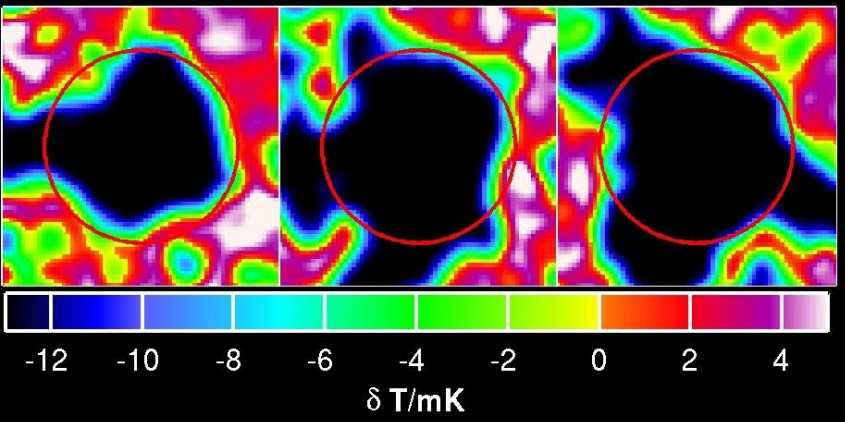
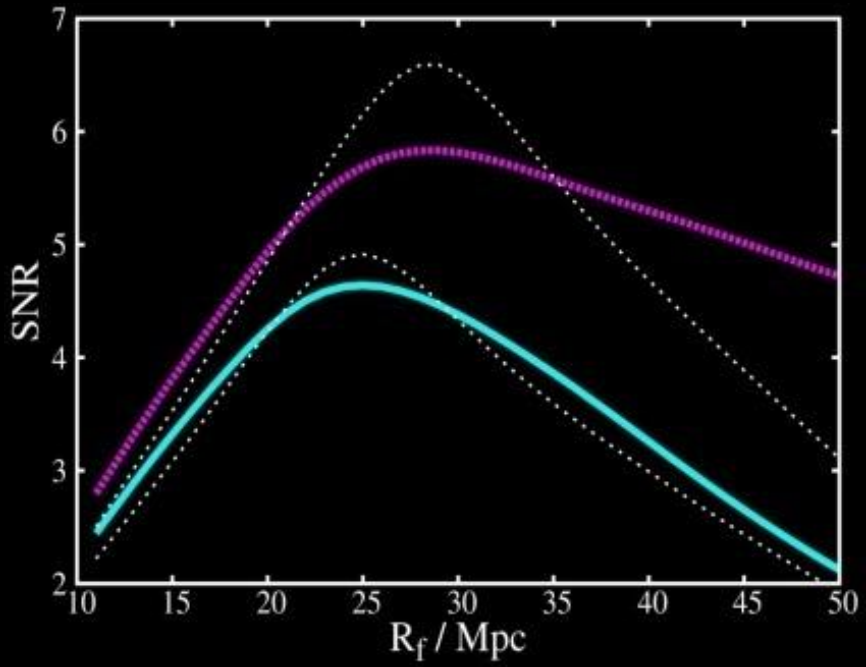




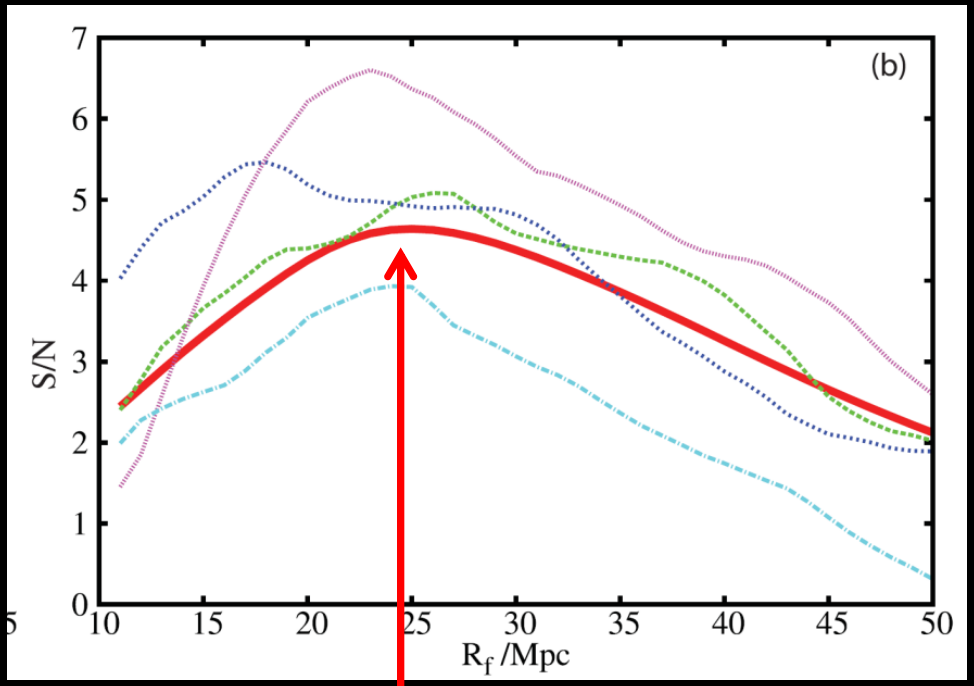
Matched filter results







What can we learn?



Predictions for
LOFAR 1200 hrs of observations

Datta et al, 2012, MNRAS, 424, Issue 1, pp. 762

We obtain ionized bubble size from the peak

	H II region size (from filter) (cMpc)	H II region size (from total photon) (cMpc)
Early quasar	11.6	12.0
Late quasar	16.0	16.4
	19.4 pm 4.06	19.7
Large box	24.9 pm 4.00	25.1

What can we learn?

H II region size from matched filter

What can we learn?

H II region size from matched filter

No other information about the QSO

Lower limit on QSO age=size/c

Uper limit on ionizing photon luminosity

$$\dot{N}_{\gamma}^{\mathrm{qso}} \lesssim \left(R_{\mathrm{b}}^{2} \frac{4}{3} \pi n_{\mathrm{c}} - \frac{N_{\gamma}^{*}}{R_{\mathrm{b}}} \right) c\,(1+z)$$

What can we learn?

H II region size from matched filter

No other information about the QSO

If ionizing luminosity is known

Lower limit on QSO age=size/c

We obtain QSO age

Uper limit on ionizing photon luminosity

$$\dot{N}_{\gamma}^{\mathrm{qso}} \lesssim \left(R_{\mathrm{b}}^{2} \frac{4}{3} \pi n_{\mathrm{c}} - \frac{N_{\gamma}^{*}}{R_{\mathrm{b}}} \right) c\,(1+z)$$

Summary

1. LOFAR like instruments should be able to detect individual QSO ionized regions in HI 21-cm with ~1200 hrs of observations

2. HII region sizes can be measured with good accuracy

3. This kind of measurements could constrain QSO age, luminosity etc

Simulations with QSO

	$\langle \dot{N}_\gamma^* \rangle$ (s)	$\dot{N}_\gamma^{qso}$ (s)	$M_{h,max}$ ($M_\odot$)	N_γ^*	N_γ^{qso}
Early QSO	4.5×10^{54}	3.3×10^{55}	4.9×10^{11}	2.5×10^{70}	2.5×10^{70}
Late QSO	1.7×10^{55}	1.4×10^{56}	6.9×10^{11}	9.8×10^{70}	1.0×10^{71}
Large box	4.3×10^{55}	2.4×10^{56}	1.2×10^{12}	2.2×10^{71}	1.7×10^{71}

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Total photon emitted by stars and the QSO

Simulations with QSO

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Photon emission rate during active QSO phase